Statistical Analysis of Codling Moth Prevalence and Fruit Damage Data

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Summary

This document describes the results of a detailed statistical analysis of field codling moth (CM) and harvest fruit damage data for years 2010 to 2013. As discussed in the meeting, the harvest fruit damage data for the year 2012 are excluded because the harvest samples were taken only from high damage level orchards. The analyses for each of the three SIR zones are presented. Furthermore, the analysis showed that there is a considerable variation in CM prevalence and fruit damage between the geographic areas within each zone. The areas with high CM prevalence and fruit damage are identified.

Two main analyses were conducted:

1. To understand the relationship between the CM prevalence and orchard size (categorized as <1, 1-2, 2-3, 3-4 and >4 hectare) in different geographic areas and over four years;

2. To understand the relationship between the fruit damage and orchard size in different geographic areas and over three years.

General Conclusions: The graphical and analytical statistical methods show very different trends of CM infestation and the resulting fruit damage. **In general, the moth infestation and fruit damage decrease with the orchard size increasing.** There was considerable variation over the geographic areas with-in the three Zones.

Overall, Zone 1 showed the lowest levels with respect to both outcomes and also relative stability over the years 2010-13. **The moth infestation and fruit damage levels went up in zones 2 and 3 after the year 2010** and some geographic areas in these zones had unusually elevated levels in the year 2013.

In the following, a short summary of the results is provided for quick reading. Detailed graphical and statistical analyses are given in sections 1 and 2.

Summary: Moth Prevalence

Moth prevalence, referring to the level of codling moth infestation, is measured using two outcomes:

(1) mean number of moths caught per trap per week in an orchard;
(2) total number of moths caught in a trap during the whole season.

Table S1 and Figure S1show the mean number of moths caught per trap per week by zone and orchard size in years 2011-2013. It is seen that the moth infestation increased significantly after 2010 in Zones 2 and 3 in all sized orchards. Zone 1 has been stable over these years. Infestation deceases with increasing orchard size in all zones and years.

Table S1 Summary of mean number of moths caught per trap per week in orchards

	Year	Orchard Size				
		<1 ha	1-2 ha	2-3 ha	3-4 ha	>4 ha
Zone 1	2010	0.14	0.11	0.08	0.05	0.10
	2011	0.14	0.11	0.08	0.05	0.03
	2012	0.08	0.07	0.06	0.02	0.04
	2013	0.05	0.04	0.04	0.02	0.04
Zone 2	2010	0.25	0.22	0.16	0.21	0.12
	2011	0.57	0.81	0.66	0.64	0.46
	2012	0.82	0.87	0.90	0.80	0.49
	2013	0.71	0.77	0.80	0.64	0.39
Zone 3	2010	0.31	0.30	0.28	0.03	0.09
	2011	0.54	0.63	0.37	0.26	0.21
	2012	0.80	0.96	0.63	0.45	0.40
	2013	0.73	0.76	0.61	0.48	0.42

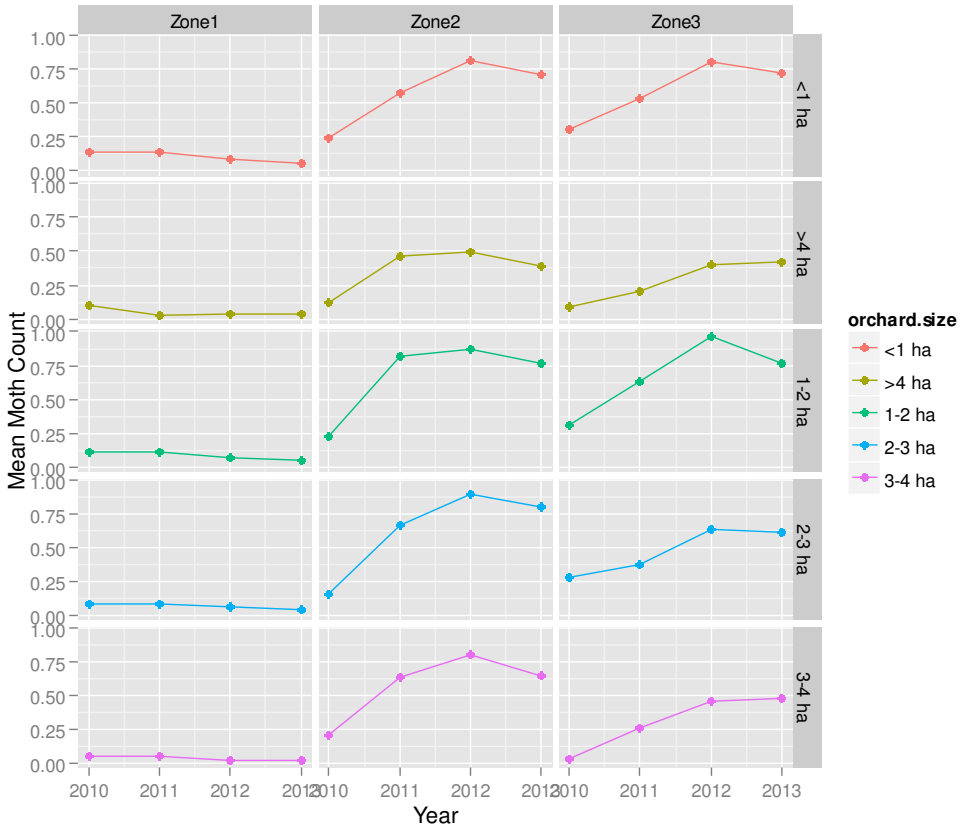

Figure S1 Mean number of moths caught per trap per week in orchards

Another way to measure moth infestation is by counting what percent of the traps were moth-free (that is, clean traps) during the whole season in a given year. That way the number of moth caught is irrelevant – a trap is either "clean" or "dirty".

Note that this summary is based on data extending up to year 2008 provided to me after the March 17 meeting. Detailed analysis is given in Section 1.3. Table S2 and Figure S2 show the percent of clean traps over the years 2008-2013 in three zones and by orchard size. In Zone 1, the percent has been around 75% during all these years. Zones 2 and 3 have a large percent of traps with moth presence. The percent of clean traps in these zones deceased significantly after the year 2010 in all sized orchards. In summary, this analysis confirms the earlier conclusion based on the mean number of moths caught in the traps.

Table S2 Percent of traps with no moth caught during the season

	Year	Orchard Size				
		<1 ha	1-2 ha	2-3 ha	3-4 ha	>4 ha
Zone 1	2008	66.7	68.1	71.9	77.5	81.3
	2009	66.0	69.1	79.0	75.6	76.3
	2010	60.4	58.9	62.6	69.4	71.0
	2011	69.8	64.0	71.6	75.5	79.6
	2012	77.8	76.2	81.0	85.0	84.3
	2013	74.3	77.5	80.6	83.4	88.9
Zone 2	2008	28.7	32.7	29.9	32.6	33.3
	2009	25.5	45.7	54.1	49.7	52.3
	2010	36.4	37.4	49.3	45.1	55.8
	2011	30.4	23.3	24.2	33.8	32.5
	2012	29.2	19.9	30.5	27.1	34.9
	2013	30.4	28.0	29.3	28.1	31.9
Zone 3	2008	27.3	31.6	39.3	49.9	38.2
	2009	31.9	26.0	34.0	58.1	45.0
	2010	34.2	36.9	39.8	54.5	52.7
	2011	16.1	20.5	28.6	45.1	33.1
	2012	24.8	17.0	22.0	25.3	23.3
	2013	25.2	18.0	15.5	36.6	18.7

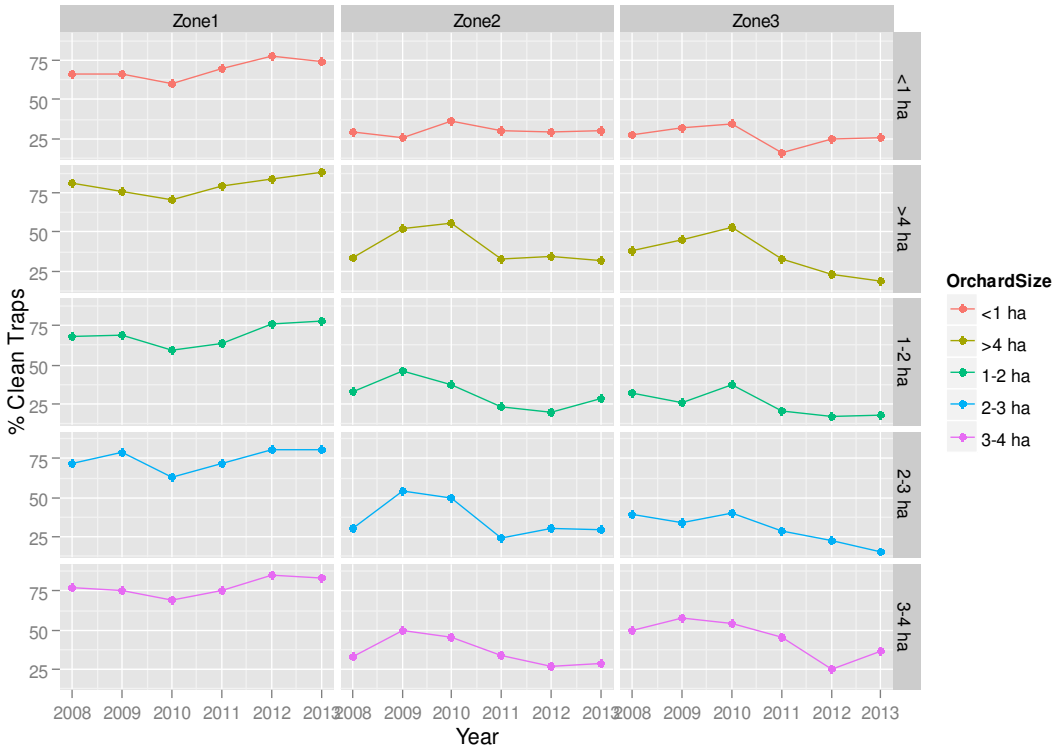

Figure S2 Percent of traps with no moth caught during the season

Summary: Harvest Sampling Results

Fruit damage by codling moth infestation is measured by sampling a number of fruit around the harvest time in the sampled orchards. The total number of fruit sampled varies depending on the size of the orchard. Typical sample size is 500 fruit but can be as high as 5000 for large orchards. For summary displays, we use the percent of fruit damaged

$$\%Damage = \frac{100 \times Number\ of\ fruit\ damaged}{Total\ number\ of\ fruit\ sampled}$$

in an orchard.

Table S3 and Figure S3show the percent fruit damage by orchard size and year for the three zones. Note that data from the year 2012 are not used in this analysis because of selective (non-random) sampling during that year.

From this summary, we observe that fruit damage did rarely go above 0.10% (one damaged fruit in 1000) on average in Zone 1. In comparison, the damage was much higher in Zones 2 and 3, especially after the year 2010. The damage level goes down with the orchard size during all years in Zones 2 and 3. Detailed statistical analysis results are presented in Section 2 later in this report.

Table S3 Percent fruit damage by orchard size and year

	Year	Orchard Size				
		<1 ha	1-2 ha	2-3 ha	3-4 ha	>4 ha
Zone 1	2010	0.03	0.01	0.02	0.02	0.05
	2011	0.10	0.08	0.01	0.00	0.01
	2013	0.11	0.07	0.00	0.02	0.09
Zone 2	2010	0.20	0.39	0.37	0.45	0.08
	2011	0.65	0.57	0.60	0.60	0.14
	2013	0.49	0.81	0.41	0.63	0.13
Zone 3	2010	0.49	0.30	0.17	0.23	0.07
	2011	1.63	1.01	0.51	0.92	0.25
	2013	1.19	0.89	1.14	1.42	0.62

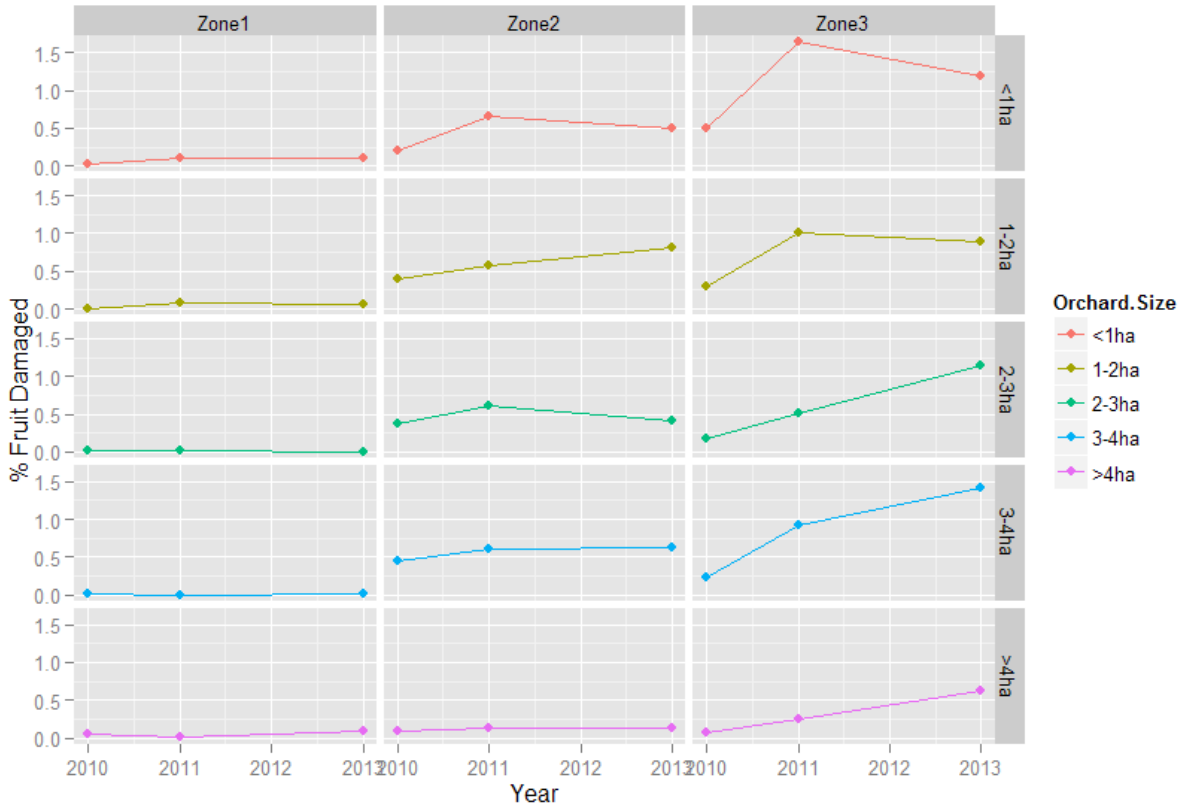

Figure S3 Percent of fruit damage by orchard size and year

1. Moth Prevalence Data

In this report codling moth prevalence is measured using two outcomes:

(a) **Orchard level outcome:** the mean number of moths caught per trap in one week. For example, if five traps were installed in an orchard, data are aggregated at the orchard level. Sections 1.1 and 1.2 in the following describe results of analysis of moth prevalence as measured by orchard level outcomes.

(b) **Trap level outcome:** A trap is defined to be "clean" if no moths were caught in it during the whole season in a given year. A clean trap indicates the absence of codling moth around the trap. A trap is defined to be "dirty" if at least one moth was caught during the season. For example, if five traps were installed in an orchard, five data values from this orchard are used in the analysis. Section 1.3 describes the analysis of trap level outcomes. Section 1.3 has been added after the March 17 meeting.

1.1 Graphs and Charts

First we look at some graphical displays to visualize the levels and variation of CM prevalence between different geographic areas and over the years 2010 to 2013. Boxplots of moth trap counts per trap per week are displayed in the following.

A boxplot is a better display than a bar chart as it reveals both the average (median) level and variation between the orchards. In a boxplot, the rectangular box shows the middle half (25^{th} percentile to 75^{th} percentile values). The horizontal line within the box indicates the median value. The dots at the higher values indicate unusually large values ("outliers") of CM counts in some of the orchards. Side-by-side boxplots are a useful tool to compare different geographic areas within and across different years.

1.1.1 Zone 1

Geographic Areas: Figure 1 shows how the CM prevalence trend changed over the last four years in the six geographic regions in Zone 1. Four areas Naramata, Oliver, Osoyoos and Similkimeen in the southern region of Zone 1 showed a downward trend between 2010 and 2013. In the other two areas of Penticton and Summerland, there is apparent change during this period. Overall, Narmata, Penticton and Summerland have higher prevalence than southern areas of Oliver, Osoyoos and Similkimeen. Zone 3 on average, had less than 0.5 Moth count per trap (over the whole season) in 2013. For a few orchards did the moth counts exceed 2 moths per trap per week.

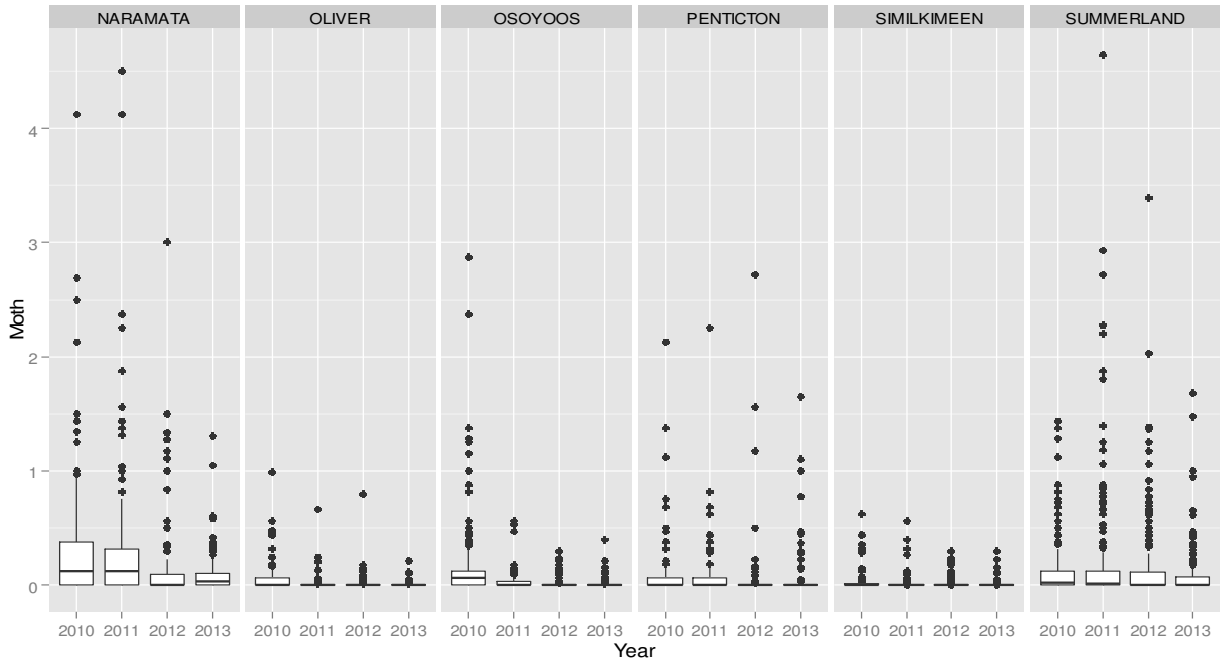

Figure 1 Boxplots of CM trap counts per week per trap in Zone 1areas during 2010-13

Orchard Size:

Figure 2 shows that CM prevalence decreases with the orchard size increasing. This trend prevailed over the years 2010-13. Smaller than 2 hectare orchards consistently show relatively elevated moth counts. The CM prevalence, overall, did not show any trend over the years 2010-2013.

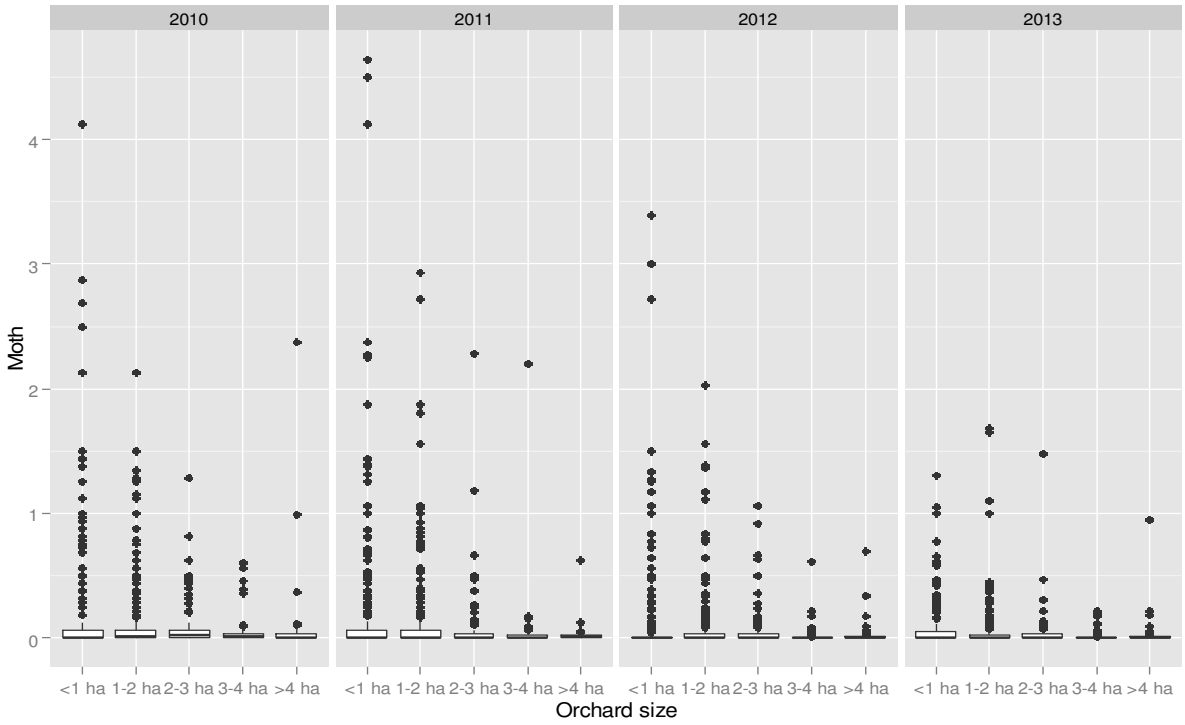

Figure 2 Boxplots of CM trap counts per week per trap by orchard size, Zone 1 during 2010-13

1.1.2 Zone 2

Figures 3 and 4 show the distribution of CM trap counts in Zone 2 orchards in various geographic areas of Zone 2 during the period 2010 to 2013. In comparison to Zone 1, the overall infestation level is much higher - the scale along the vertical axis in these figures goes up to 15 moths caught per week per trap.

Geographic Areas: The trap counts clearly show an increase in infestation from the 2010 level to 2013 in almost all geographic areas. Infestation was noticeably higher during 2012-13 in Belgo, East Kelowna, Okanagan Mission and South Kelowna.

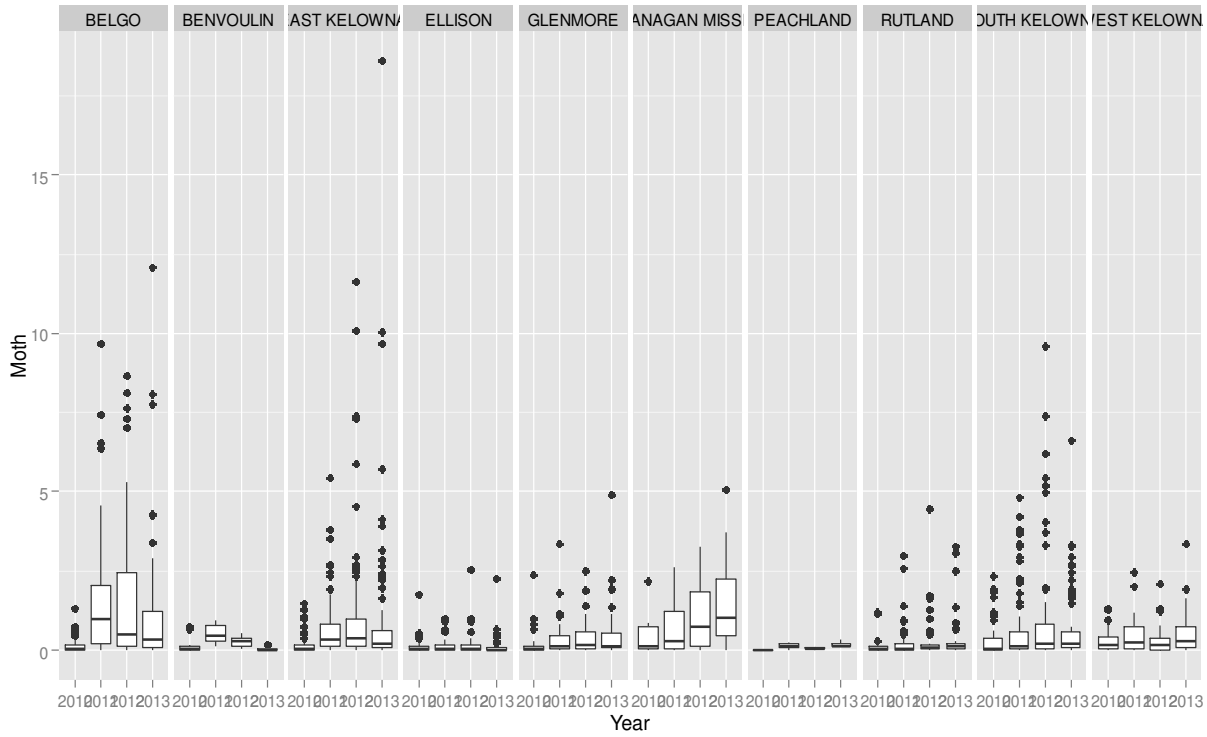

Figure 3 Boxplots of CM trap counts per week per trap in Zone 2 areas during 2010-13

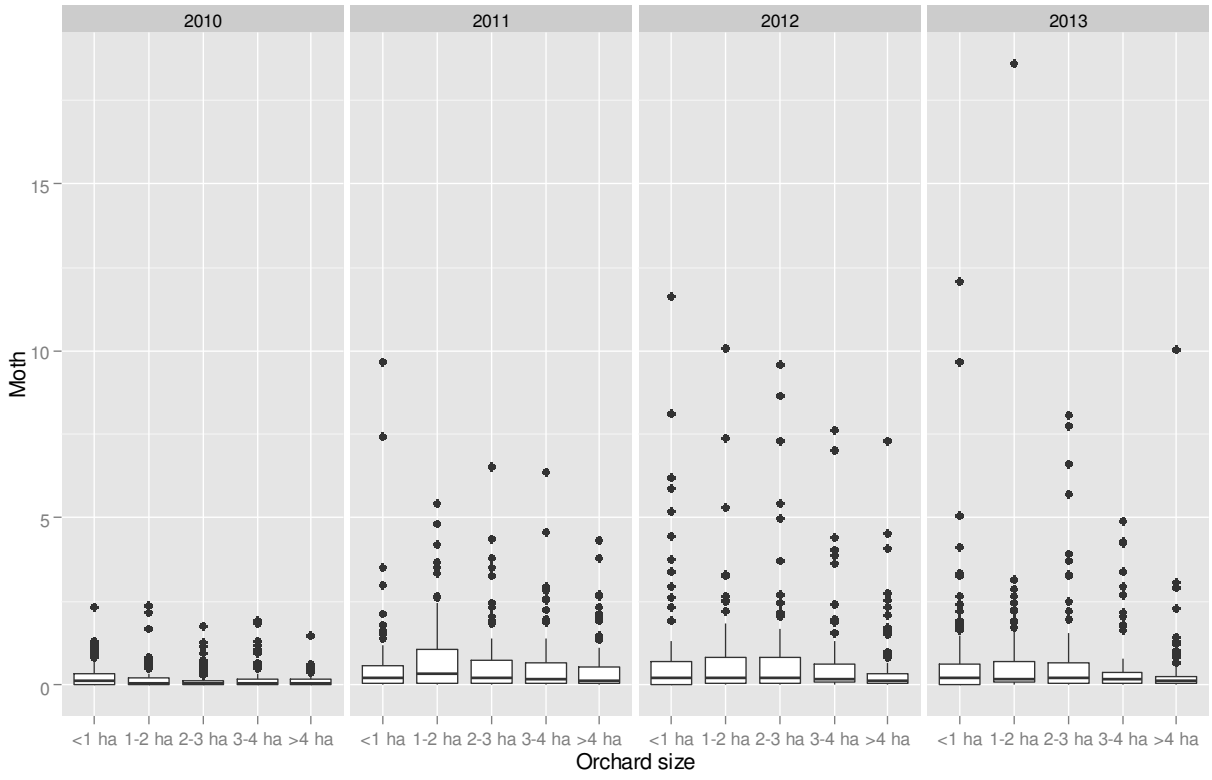

Figure 4 Boxplots of CM trap counts per week per trap by orchard size, Zone 2 during 2010-13

Orchard Size (Figure 4): Variation in CM infestation in orchards of different sizes in Zone 2 is not as clear as it was for Zone 1 orchards. Overall, the orchard size does not seem to have any effect on moth prevalence. Overall, the infestation level jumped up after 2010 in orchards of all sizes.

1.1.3 Zone 3

Geographic Areas: The overall levels of CM infestation in Zone 3 orchards are comparable to those in Zone 2. There is a clear trend showing that infestation had consistently got worse after the year 2010 in all the geographic areas.

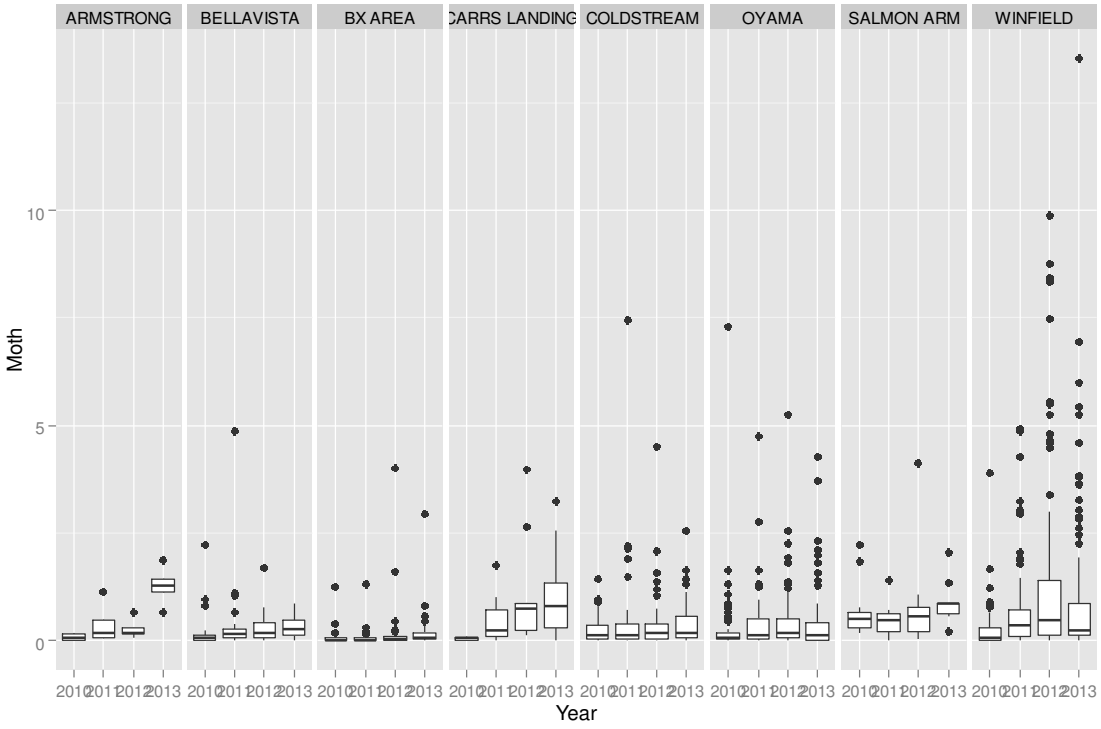

Figure 5 Boxplots of CM trap counts per week per trap in Zone 3 areas during 2010-13

Orchard Size: As seen in Figure 6, the CM infestation levels in Zone 3 orchards don't vary with orchards size in any consistent manner. However, the upward trend after the year 2010 is very clear.

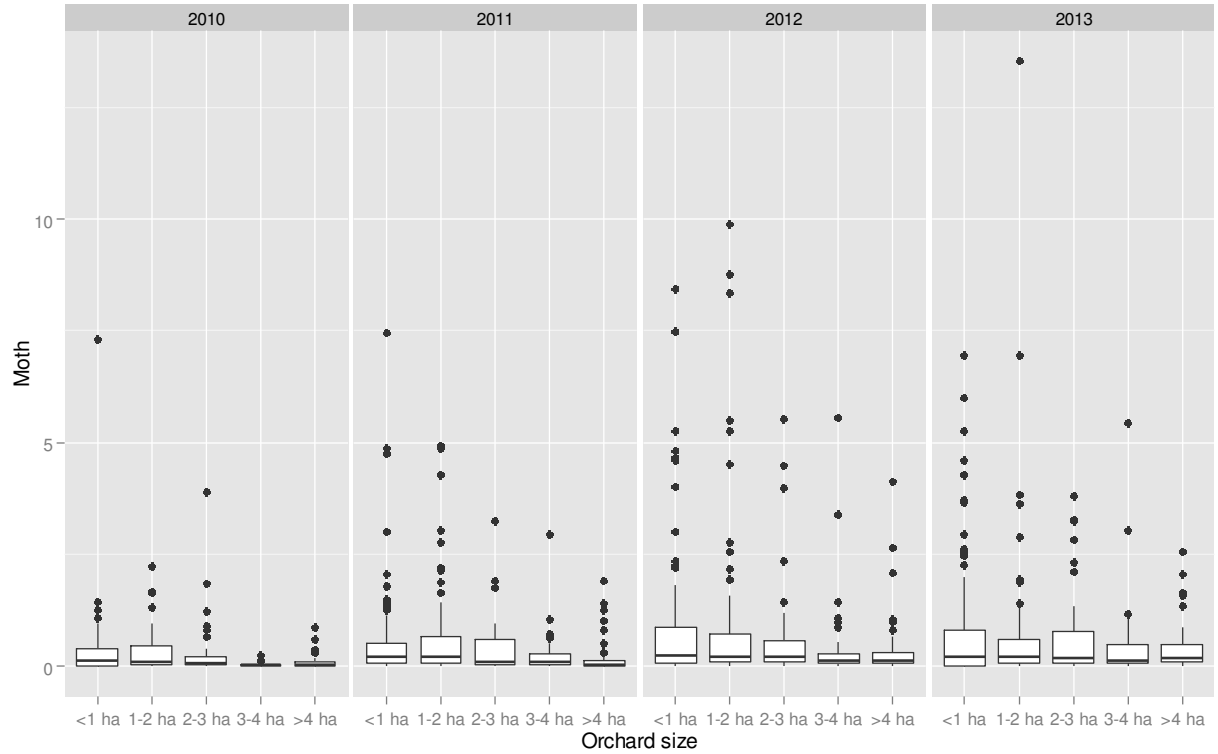

Figure 6 Boxplots of CM trap counts per week per trap by orchard size, Zone 3 during 2010-13

1.2 Analysis of Variance for CM Data

Analysis of variance (ANOVA) is a formal statistical method to analyze the differences in the infestation levels of CM in different years, in orchards of different sizes and in various geographic areas of a zone. The basic idea is to decompose the total variability (sum of squares) into various parts representing the contribution of factors: orchard size, geographic area and years. The magnitude of the effect of a factor is statistically judged by the value of the F statistic (called the F value). Larger the F value, more significant is the contribution of the associated factor in explaining the variation in the data.

In the following, results of ANOVA for the CM trap counts are presented.

1.2.1 Zone 1

In the analysis of variance Table 1, the F values for all the three factors: Orchard size, geographical areas and years are statistically significant. That is, In Zone 1, the CM prevalence levels vary with the orchard size, in different geographical areas and during the years 2010-2013. However, it is important to note that most of the variation in trap counts remains unaccounted for. This is reflected in the residuals sum of squares value (311.53 out of total 338.55). The geographical areas explain the highest share of variation about 6.5% (22.00 out of total 338.55).

Table 1 ANOVA for Zone 1, significant p-values shown in red

Factor	Df	Sum Sq	Mean Sq	F value	p-value
Orchard size	4	1.816	0.454	5.74	0.0
Areas	5	22.002	4.400	55.59	0.0
Years	3	3.198	1.066	13.47	0.0
Residuals	3936	311.53	0.079		
Total	3948	338.55			

Table 2 shows a comparison of various levels of factors for their effect on the CM counts per week per trap. As the orchard size is dividing into 5 groups (<1, 1-2, 2-3, 3-4, and >4 hectare), the lowest orchard size (< 1 hectare) is used as a baseline against which the higher orchard sizes are compared. Even though the CM prevalence decreases with orchard size indicated by the negative values of estimates, the differences are not statistically significant as none of the p-values are less than 5% significance level.

The geographic areas of Oliver, Osoyoos and Similkimeen have significantly lower infestation levels than Narmata, Penticton and Summerland. Over the years, infestation decreased significantly from the 2010 infestation levels during 2012 and 2013.

Table 2 Comparison of factors for Zone 1, significant p-values shown in red

Factor	Estimate	Std. Err	t value	p-value
Orchard size: <1 ha baseline				
1-2 ha	-0.012	0.0104	-1.144	0.25
2-3 ha	-0.022	0.0149	-1.456	0.15
3-4 ha	-0.035	0.0184	-1.887	0.06
> 4 ha	-0.018	0.0226	-0.8	0.42
Geographic Areas: NARMATA baseline				
OLIVER	-0.207	0.016	-12.725	0.0
OSOYOOS	-0.159	0.018	-8.816	0.0
PENTICTON	-0.114	0.020	-5.548	0.0
SIMILKIMEEN	-0.213	0.016	-13.712	0.0
SUMMERLAND	-0.079	0.016	-4.96	0.0
Year 2010 baseline				
Year 2011	-0.004	0.0125	-0.343	0.73
Year 2012	-0.043	0.0126	-3.433	0.0
Year 2013	-0.069	0.0126	-5.45	0.0

1.2.2 Zone 2

Table 3 ANOVA shows that the CM prevalence in Zone 2 varies significantly by orchard size, geographic areas and over the years 2010 to 2013. In Zone 2 also, the geographic areas and the years explain more variation in the trap counts than explained by the orchard size. But 90% of the total variation remains unexplained with the residual sum of squares value of 2636.82.

Table 3 ANOVA for Zone 2, significant p-values shown in red

Factor	Df	Sum Sq	Mean Sq	F value	p-value
Orchard size	4	21.76	5.44	3.68	0.0
Areas	9	174.14	19.34	13.09	0.0
Years	3	89.58	29.86	20.21	0.0
Residuals	1785	2636.82	1.477		
Total	1801	2918.30			

Table 4 Comparison of factors for Zone 2, significant p-values shown in red

Factor	Estimate	Std. Err	t value	p-value
Orchard size: <1 ha baseline				
1-2 ha	0.088	0.091	0.974	0.33
2-3 ha	0.061	0.090	0.675	0.50
3-4 ha	-0.035	0.095	-0.366	0.71
> 4 ha	-0.197	0.089	-2.209	0.03
Geographic Areas: BELGO baseline				
BENVOULIN	-0.880	0.178	-4.954	0.0
EAST KELOWNA	-0.465	0.100	-4.655	0.0
ELLISON	-1.038	0.114	-9.082	0.0
GLENMORE	-0.863	0.119	-7.276	0.0
OKANAGAN MISSION	-0.194	0.229	-0.848	0.40
PEACHLAND	-1.032	0.361	-2.859	0.0
RUTLAND	-0.849	0.124	-6.863	0.0
SOUTH KELOWNA	-0.502	0.108	-4.636	0.0
WEST KELOWNA	-0.765	0.139	-5.519	0.0
Year 2010 baseline				
Year 2011	0.434	0.080	5.390	0.0
Year 2012	0.580	0.080	7.215	0.0
Year 2013	0.470	0.081	5.802	0.0

Table 4 shows a comparison of various levels of factors for their effect on the CM counts per week per trap in Zone 2. With respect to the orchard size, CM prevalence patterns are not clear because the analysis compares orchards with <1 hectare orchards. There is some evidence that

CM prevalence may have decreased for larger orchards (over 4 hectare size). Further analysis based on multiple comparisons, however, did not show statistically significant results. Almost all geographic areas show significantly lower infestation levels than Belgo. Infestation levels increased significantly after the year 2010 and stayed at about those levels in 2012-2013.

1.2.3 Zone 3

As shown in the ANOVA Table 5, the three factors though statistically significant, the Areas and Years factors have larger value for Sum of Squares than that for the orchard size. That is, most of the variation in the CM prevalence was over the three years. This is further confirmed by the effect comparisons in Table 6 where we see that the years 2011 to 2013 showed significant increase in infestation levels after the year 2010.

Table 5 ANOVA for Zone 3, significant p-values shown in red

Factor	Df	Sum Sq	Mean Sq	F value	p-value
Orchard size	4	28.41	7.10	6.28	0.0
Areas	7	83.03	11.86	10.49	0.0
Years	3	41.88	13.96	12.34	0.0
Residuals	1262	1427.15	1.13		
Total	1276	1580.47			

Table 6 Comparison of factors for Zone 3, significant p-values shown in red

Factor	Estimate	Std. Err	t value	p-value
Orchard size: <1 ha baseline				
1-2 ha	0.102	0.080	1.267	0.20
2-3 ha	-0.114	0.092	-1.235	0.22
3-4 ha	-0.298	0.100	-2.995	0.0
> 4 ha	-0.189	0.098	-1.932	0.054
Geographic Areas: ARMSTRONG baseline				
BELLAVISTA	-0.098	0.290	-0.337	0.74
BXAREA	-0.263	0.278	-0.948	0.34
CARRS LANDING	0.293	0.322	0.910	0.36
COLDSTREAM	0.002	0.280	0.006	0.99
OYAMA	-0.030	0.275	-0.109	0.91
SALMON ARM	0.283	0.312	0.906	0.36
WINFIELD	0.418	0.272	1.536	0.12
Year 2010 baseline				
Year 2011	0.210	0.084	2.498	0.01
Year 2012	0.468	0.084	5.574	0.0
Year 2013	0.393	0.084	4.658	0.0

1.3 Analysis of Clean/Dirty Traps in 2008 to 2013

Based on our discussion at the March 17 meeting, I analyzed proportion of clean (moth-free) traps. The analysis is based on data sent by Shawn on March 18. Note that this dataset is extended over six years from 2008 to 2013.

1.3.1 Temporal and orchard size trends: This analysis is an alternative way of looking at moth infestation. Table 7 and Figure 7 show the overall summary of percent of clean traps by orchard size and the year for the three zones. The pattern of variation is quite clear and consistent. Zone 1 shows higher level of clean traps than the other two zones.

In Zone 2 and Zone 3, percent of moth free traps decreased after the year 2010 and remained low – indicating an increase in codling moth infestation. Overall, the infestation seems to decreasing by the orchard size in all the zones.

Table 7 Percent of traps with no moth caught during the year, by Zone, year and orchard size

	Year	Orchard Size				
		<1 ha	1-2 ha	2-3 ha	3-4 ha	>4 ha
Zone 1	2008	66.7	68.1	71.9	77.5	81.3
	2009	66.0	69.1	79.0	75.6	76.3
	2010	60.4	58.9	62.6	69.4	71.0
	2011	69.8	64.0	71.6	75.5	79.6
	2012	77.8	76.2	81.0	85.0	84.3
	2013	74.3	77.5	80.6	83.4	88.9
Zone 2	2008	28.7	32.7	29.9	32.6	33.3
	2009	25.5	45.7	54.1	49.7	52.3
	2010	36.4	37.4	49.3	45.1	55.8
	2011	30.4	23.3	24.2	33.8	32.5
	2012	29.2	19.9	30.5	27.1	34.9
	2013	30.4	28.0	29.3	28.1	31.9
Zone 3	2008	27.3	31.6	39.3	49.9	38.2
	2009	31.9	26.0	34.0	58.1	45.0
	2010	34.2	36.9	39.8	54.5	52.7
	2011	16.1	20.5	28.6	45.1	33.1
	2012	24.8	17.0	22.0	25.3	23.3
	2013	25.2	18.0	15.5	36.6	18.7

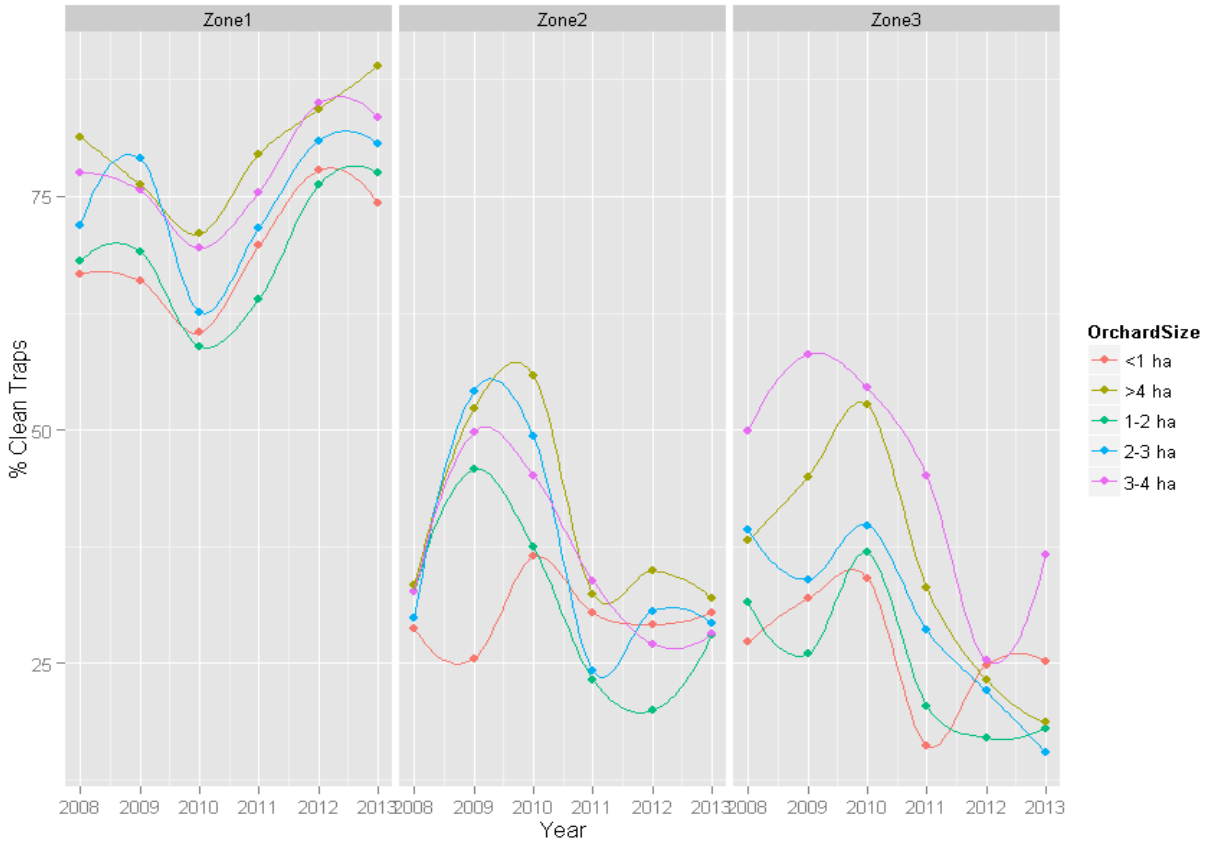

Figure 7 Percent of traps with no moth caught during the year, by Zone and orchard size

1.3.2 Statistical Analysis: For the purpose of statistical analysis, the count of clean traps out of total number of traps aggregated at the year and orchard size combination for each geographic area in a Zone is used. The formal model is called the Binomial generalized linear model. This model compares the logarithm of odds of a trap being clean.

Zone 1: Table 8 shows the details of results from the generalized linear model analysis for Zone 1. We see that the orchard size is a significant factor. The proportion of clean traps increases significantly with increasing orchard size more than 2 hectares indicating lower infestation levels for larger orchards. For the between years comparison, the year 2008 is used as the baseline. The temporal trend indicates that infestation increased significantly in 2010 but then dropped significantly in 2012 and 2013.

Table 8 Comparison of factors for codling moth in Zone 1, significant p-values in red

Factor	Estimate	Std. Error	z value	p-value
Orchard size: <1 ha baseline				
1-2 ha	0.050	0.060	0.840	0.40
2-3 ha	0.204	0.071	2.874	0.0
3-4 ha	0.558	0.084	6.638	0.0
> 4 ha	0.409	0.079	5.154	0.0
Geographic Areas: NARMATA baseline				
OLIVER	1.709	0.086	19.813	0.0
OSOYOOS	0.923	0.090	10.235	0.0
PENTICTON	1.199	0.103	11.652	0.0
SIMILKIMEEN	2.398	0.084	28.551	0.0
SUMMERLAND	0.392	0.077	5.096	0.0
Year 2008 baseline				
2009	0.085	0.078	1.098	0.27
2010	-0.434	0.075	-5.781	0.0
2011	0.023	0.080	0.287	0.77
2012	0.386	0.083	4.631	0.0
2013	0.435	0.083	5.215	0.0

Zone 2: Analysis results for Zone 2 are shown in Table 9. Here also, we see that the orchard size is a significant factor. The proportion of clean traps increases significantly with increasing orchard size more than 2 hectares indicating lower infestation levels for larger orchards.

Over the years, the infestation levels dropped in 2009/2010 from the 2008 levels but then increased significantly in 2011 and remained at high levels.

Table 9 Comparison of factors for codling moth in Zone 2, significant p-values in red

Factor	Estimate	Std. Error	z value	p-value
Orchard size: <1 ha baseline				
1-2 ha	0.050	0.122	0.412	0.68
2-3 ha	0.339	0.109	3.105	0.0
3-4 ha	0.316	0.107	2.960	0.0
> 4 ha	0.616	0.099	6.202	0.0
Geographic Areas: BELGO baseline				
EAST KELOWNA	0.159	0.083	1.913	0.06
ELLISON	1.230	0.099	12.427	0.0
GLENMORE	0.556	0.107	5.216	0.0
RUTLAND	0.235	0.099	2.378	0.02
SOUTH KELOWNA	0.166	0.095	1.742	0.08
WEST KELOWNA	-0.165	0.129	-1.284	0.20
Year 2008 baseline				
2009	0.664	0.076	8.776	0.0
2010	0.627	0.077	8.129	0.0
2011	-0.262	0.083	-3.164	0.0
2012	-0.293	0.083	-3.510	0.0
2013	-0.173	0.083	-2.079	0.04

Zone 3: Analysis results for Zone 3 are shown in Table 10. Here also, we see that the orchard size is a significant factor. The proportion of clean traps increases significantly with increasing orchard size more than 2 hectares indicating lower infestation levels for larger orchards.

Over the years, the infestation levels dropped in 2010 from the 2008-2009 levels but then increased significantly in 2012 and 2013.

Table 10 Comparison of factors for codling moth in Zone 3, significant p-values in red

Factor	Estimate	Std. Error	z value	p-value
Orchard size: <1 ha baseline				
1-2 ha	-0.012	0.128	-0.093	0.93
2-3 ha	0.386	0.124	3.104	0.0
3-4 ha	0.643	0.124	5.202	0.0
> 4 ha	0.641	0.112	5.716	0.0
Geographic Areas: BELLAVISTA baseline				
BXAREA	1.301	0.135	9.625	0.0
CARRSLANDING	-0.632	0.236	-2.678	0.01
COLDSTREAM	0.424	0.141	3.001	0.0
OYAMA	0.356	0.136	2.617	0.01
SALMON ARM	-0.765	0.208	-3.681	0.0
WINFIELD	-0.350	0.134	-2.616	0.01
Year 2008 baseline				
2009	0.143	0.109	1.308	0.19
2010	0.494	0.108	4.560	0.0
2011	-0.196	0.113	-1.736	0.08
2012	-0.717	0.118	-6.060	0.0
2013	-0.827	0.121	-6.813	0.0

2. Analysis for Fruit Damage Data

Fruit damage by codling moth infestation is measured by sampling a number of fruit around the harvest time in the sampled orchards. The total number of fruit sampled varies depending on the size of the orchard. Typical sample size is 500 fruit but can be as high as 5000 for large orchards. For graphical displays, we use the percent of fruit damaged

$$\%Damage = \frac{100 \times Number\ of\ fruit\ damaged}{Total\ number\ of\ fruit\ sampled}$$

in an orchard. It is well known that the sample size itself affects the variation in the %Damage. Therefore, the standard analysis of variance (ANOVA) method is not strictly applicable. This is particularly the case when the damage level is low as we have the case for moth-damaged fruit - most of the orchards show no or negligible damage (less than 1%).

For the purpose of statistical analysis, we use the count of fruit damaged adjusted for the sample size. The formal model is called the Binomial generalized linear model.

Note: In the year 2012 the harvest damage was assessed selectively in the worst-affected orchards. Therefore, 2012 damage data are not used in the following analysis.

2.1 Zone 1

Figures 8 and 9 display the boxplots of % of fruit damaged by geographic areas and orchard size, respectively. As most of the values are at zero (indicated by a horizontal line at the bottom), the plots reveal variation only in the values above zero. In Zone 1, the damage levels rarely exceed 2%. The damage % seems to go down with the orchard size in all the years.

Statistical Significance: Table 11 shows a comparison of various levels of factors for their effect on the fruit damage levels. As the orchard size is dividing into 5 groups (<1, 1-2, 2-3, 3-4 and >4 hectare), the lowest orchard size (< 1 hectare) is used as a baseline against which the higher orchard sizes are compared. There is some evidence that fruit damage decreased with the orchard size increasing.

The geographic areas Oliver, Osoyoos and Similkimeen have significantly lower damage levels than Narmata and Penticton. Years 2011 and 2013 had slightly higher level than the year 2010.

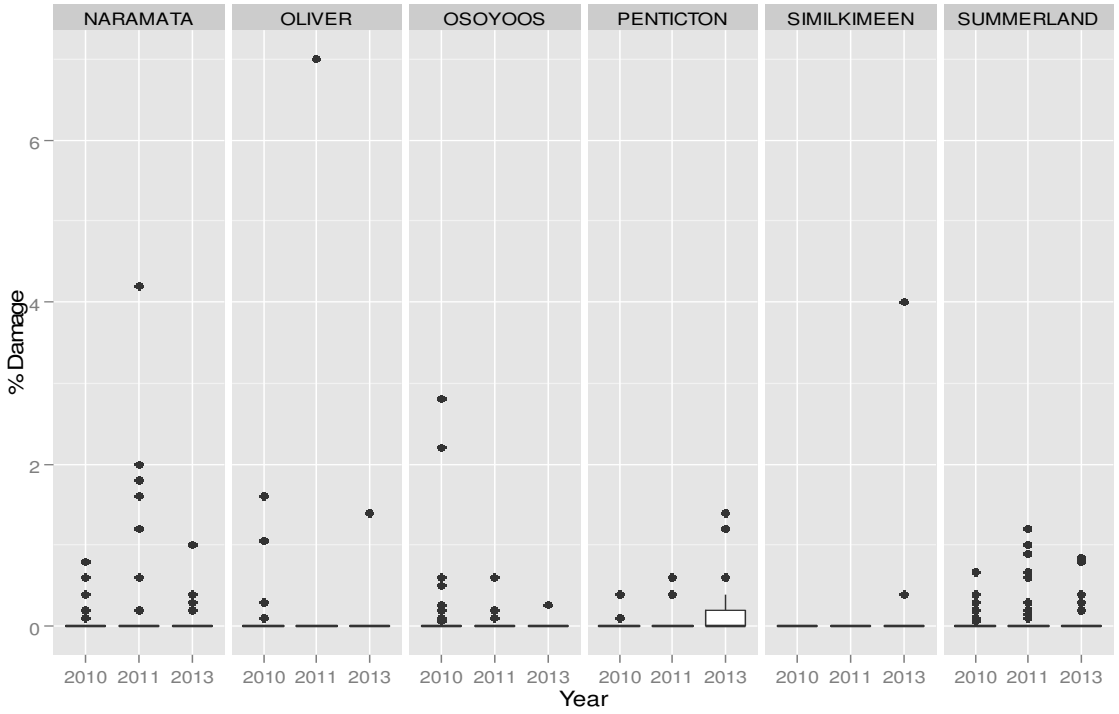

Figure 8 Boxplots of % fruit damaged in orchards by geographic areas in Zone 1 during 2010-13

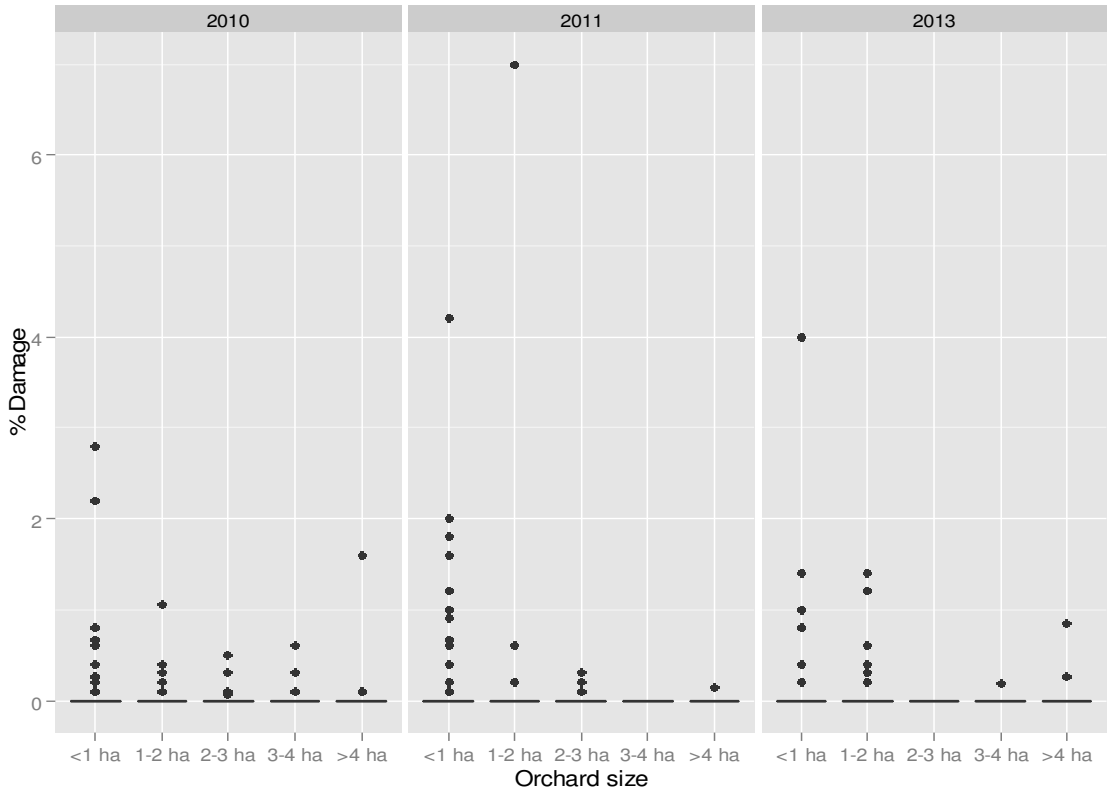

Figure 9 Boxplots of % fruit damaged by orchard size, Zone 1 during 2010-13

Table 11 Comparison of factors for fruit damage in Zone 1, significant p-values in red

Factor	Estimate	Std. Err	t value	p-value
Orchard size: <1 ha baseline				
1-2 ha	-0.536	0.120	-4.486	0.0
2-3 ha	-1.469	0.221	-6.638	0.0
3-4 ha	-1.373	0.300	-4.585	0.0
> 4 ha	0.201	0.174	1.152	0.25
Geographic Areas: NARMATA baseline				
OLIVER	-0.147	0.153	-0.960	0.34
OSOYOOS	0.114	0.165	0.694	0.49
PENTICTON	-0.251	0.195	-1.287	0.20
SIMILKIMEEN	-2.716	0.332	-8.171	0.0
SUMMERLAND	-0.444	0.143	-3.100	0.0
Year 2010 baseline				
Year 2011	1.084	0.117	9.288	0.0
Year 2013	1.171	0.135	8.642	0.0

2.2 Zone 2

Figures 10 and 11 show the boxplots of damage % in orchard in different geographic areas and by the orchard size during the years 2010, 2011 and 2013 in Zone 2. In comparison to Zone 1, we notice that the damage level values in Zone 2 orchards above 5%. There is some evidence that damage decreased by the orchard size increasing.

Statistical analysis output in Table 12 confirms that damage level did go down significantly with the orchard size. There is also statistically significant variation in fruit damage levels by the geographic areas. Benvoulin, East Kelowna, Ellison, Glenmore, Okanagan Mission and West Kelowna have lower damage levels that Belgo, Rutland and South Kelowna.

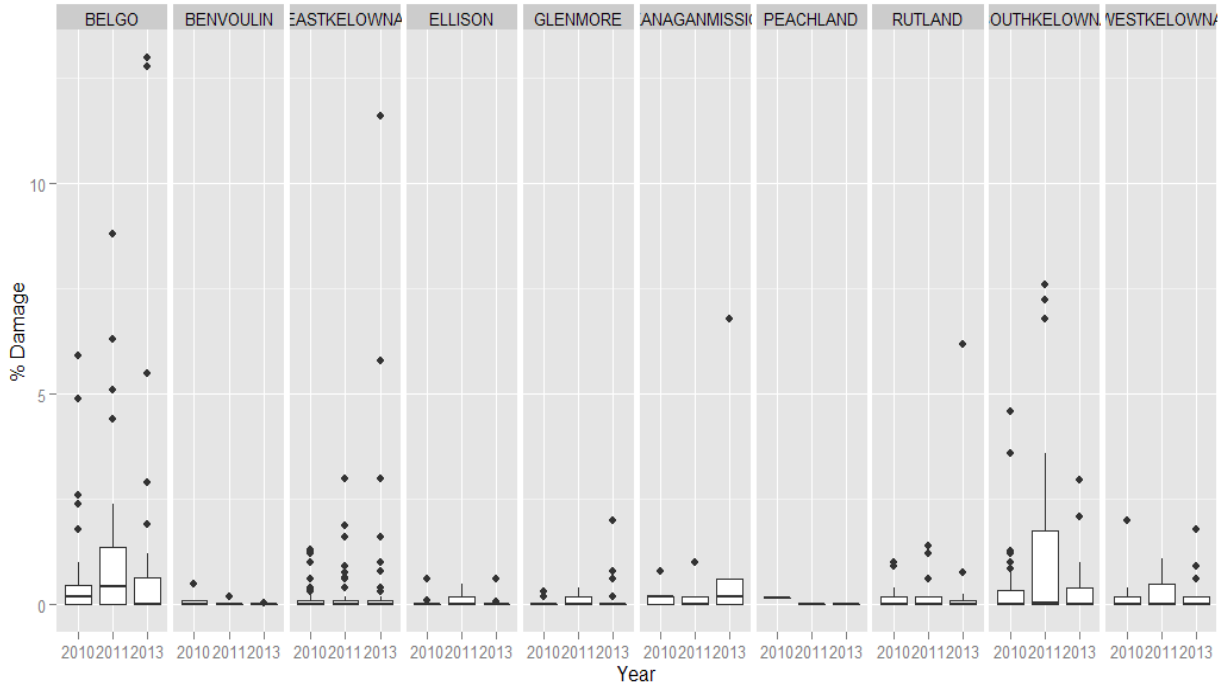

Figure 10 Boxplots of % fruit damaged in orchards by geographic areas in Zone 2 during 2010-13

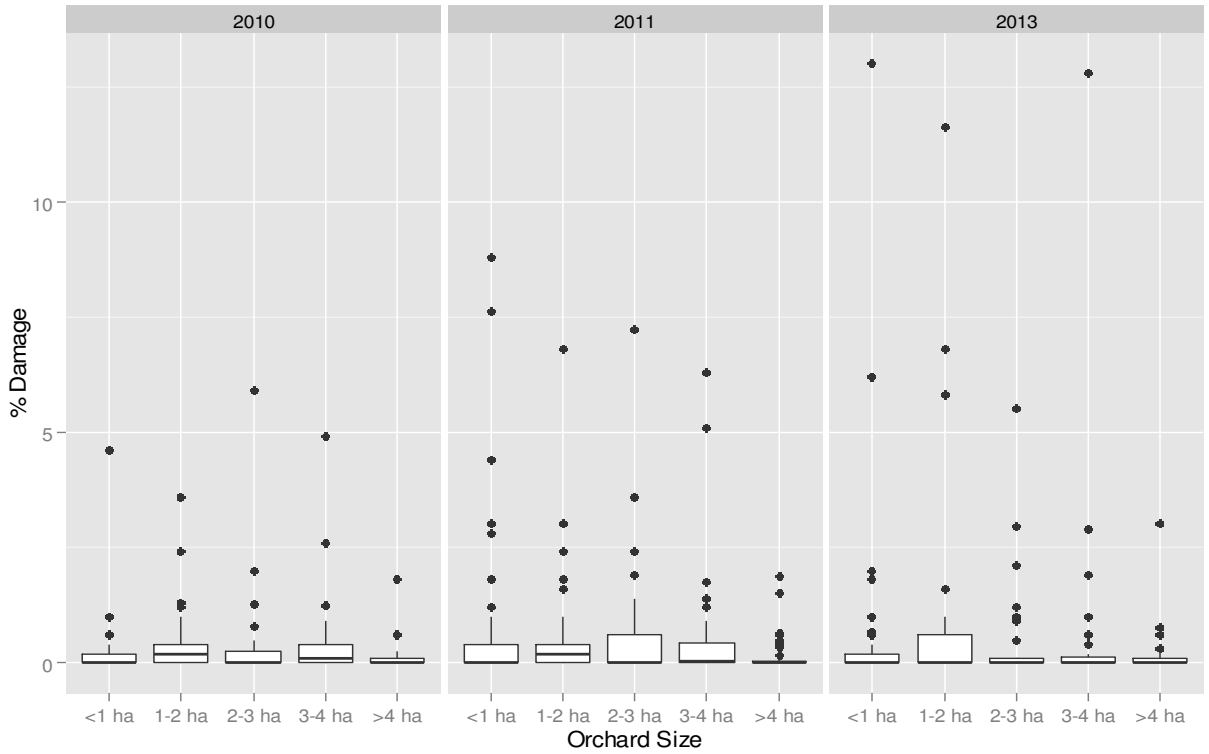

Figure 11 Boxplots of % fruit damaged by orchard size, Zone 2 during 2010-13

Table 12 Comparison of factors for fruit damage in Zone 2, significant p-values in red

Factor	Estimate	Std. Err	t value	p-value
Orchard size: <1 ha baseline				
1-2 ha	0.270	0.076	3.55	0.0
2-3 ha	0.005	0.070	0.066	0.95
3-4 ha	0.227	0.076	3.364	0.0
> 4 ha	-1.108	0.077	-14.466	0.0
Geographic Areas: BELGO baseline				
BENVOULIN	-2.963	0.335	-14.47	0.0
EAST KELOWNA	-1.390	0.060	-23.004	0.0
ELLISON	-2.211	0.141	-15.622	0.0
GLENMORE	-2.957	0.197	-15.002	0.0
OKANAGAN MISSION	-0.958	0.181	-5.283	0.0
PEACHLAND	-1.936	0.581	-3.334	0.0
RUTLAND	-1.236	0.100	-12.335	0.0
SOUTH KELOWNA	-0.400	0.058	-6.956	0.0
WEST KELOWNA	-1.536	0.118	-13.004	0.0
Year 2010 baseline				
Year 2011	0.540	0.055	9.849	0.0
Year 2013	0.479	0.056	8.583	0.0

2.3 Zone 3

Figures 12 and 13 show boxplots of damage % in orchard in different geographic areas and by the orchard size, respectively, during the years 2010-13 in Zone 3. In comparison to Zones 1 and 2, we notice that the damage level values in some Zone 3 orchards were unusually high, especially in Coldstream and Winfield during all the years. There is some evidence that damage decreases by the orchard size.

Statistical analysis output in Table 13 confirms that damage level did go down significantly with the orchard size. There is also statistically significant variation in fruit damage levels by the geographic areas. Coldstream, Oyama, Salmon Arm and Winfield orchards had higher damage levels than orchards in other areas.

The damage levels increased significantly in 2011 from the 2010 levels and remained high in 2013.

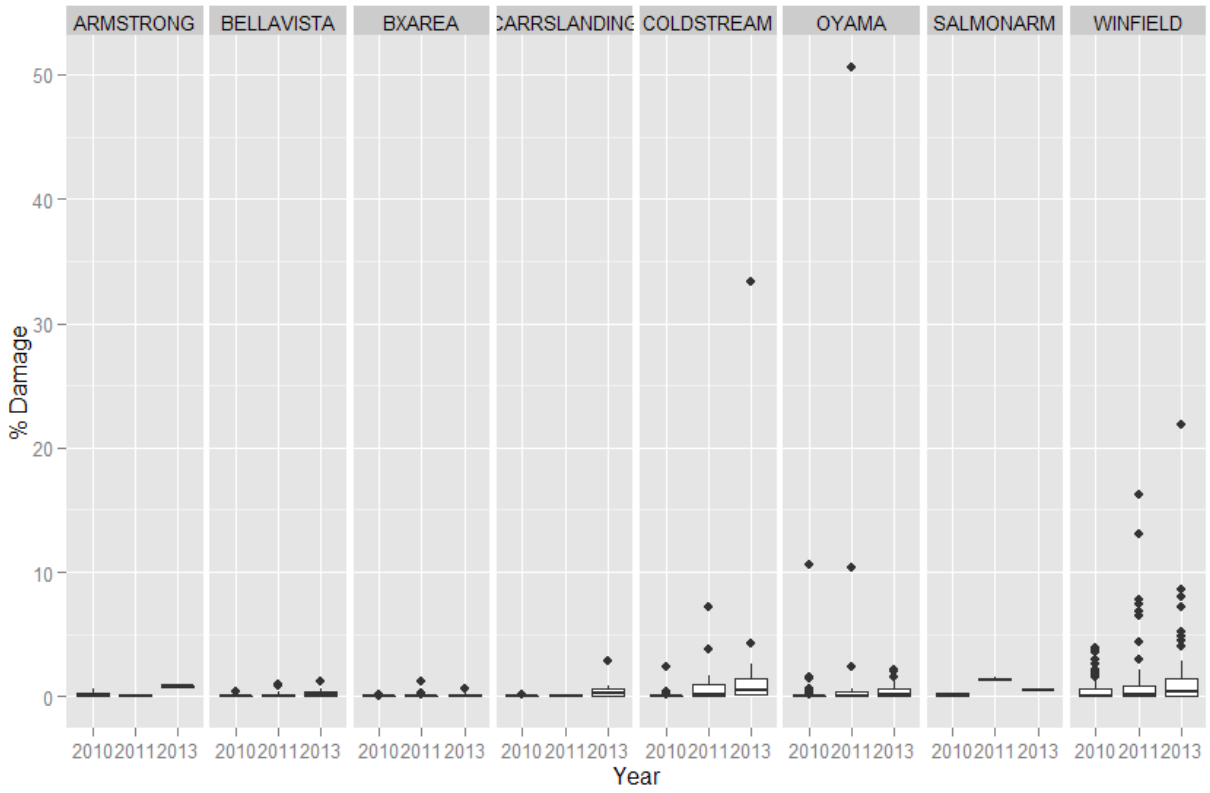

Figure 12 Boxplots of % fruit damaged in orchards by geographic areas, Zone 3 during 2010-13

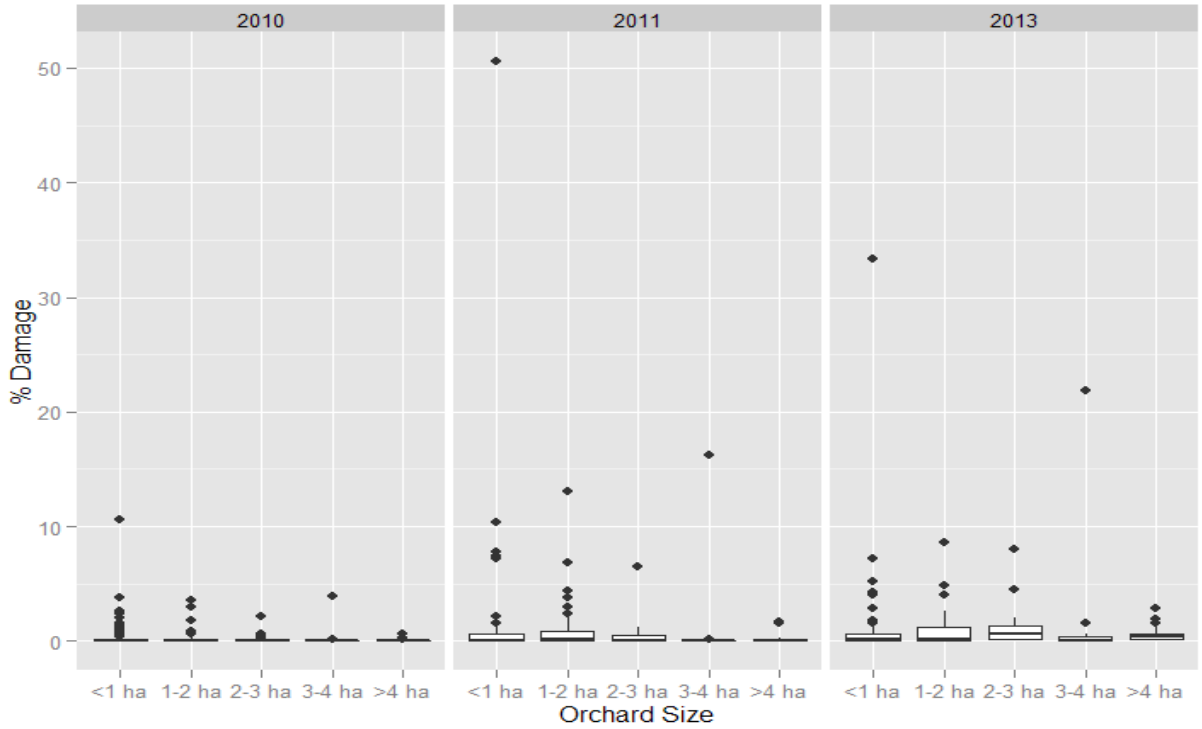

Figure 13 Boxplots of % fruit damaged by orchard size, Zone 3 during 2010-13

Table 13 Comparison of factors for fruit damage in Zone 3, significant p-values in red

Factor	Estimate	Std. Err	t value	p-value
Orchard size: <1 ha baseline				
1-2 ha	-0.407	0.056	-7.244	0.0
2-3 ha	-0.439	0.064	-6.916	0.0
3-4 ha	-0.040	0.056	-0.706	0.48
> 4 ha	-0.974	0.071	-13.776	0.0
Geographic Areas: ARMSTRONG baseline				
BELLAVISTA	-0.434	0.285	-1.522	0.13
BXAREA	-1.336	0.283	-4.723	0.0
CARRS LANDING	-0.287	0.306	-0.938	0.35
COLD STREAM	1.176	0.256	4.599	0.0
OYAMA	0.951	0.255	3.730	0.0
SALMON ARM	1.285	0.290	4.436	0.0
WINFIELD	1.293	0.253	5.228	0.0
Year 2010 baseline				
Year 2011	1.179	0.060	19.507	0.0
Year 2013	1.258	0.060	20.948	0.0